

## MUSICOS 1998: Optical and X-rays Observations of Flares on the RS CVn Binary HR 1099

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**Abstract.** We present simultaneous and continuous observations of  $H\alpha$ ,  $H\beta$ ,  $\text{Na I D}_1$ ,  $\text{D}_2$  and  $\text{He I D}_3$  lines of the chromospherically active binary HR 1099. We have observed HR 1099 for more than 3 weeks almost continuously and monitored two flares. An increase in  $H\alpha$ ,  $\text{Ca II H}$  &  $\text{K}$ ,  $H\beta$ ,  $\text{He I D}_3$  and  $\text{He I } \lambda 6678$  and a strong filling-in of the  $\text{Na I D}_1$ ,  $\text{D}_2$  and  $\text{Mg I b}$  triplet during one of the flares are observed. We have found that the flares took place at the same phase (0.85) of the binary orbit, and both of them seems to occur near the limb. Several X-rays flares were also detected by ASM on board RXTE. Rotational modulation in the X-rays light curve has been detected with maximum flux when the active K1IV star is in front.

### 1. Introduction

HR 1099 is a triple system and consists of a close double-lined spectroscopic pair with a spotted and rapidly rotating K1IV primary and a comparably inactive and slowly rotating G5V secondary in a 2<sup>d</sup>8 orbit. The tertiary is a fainter K3V star 6'' away. The system HR 1099 is one of the few RS CVn systems, along with UX Ari, II Peg, and DM UMa, that shows  $H\alpha$  consistently in emission. Its tidally induced rapid rotation, combined with the deepened convection zone of a post main sequence envelope, is responsible for the very high chromospheric activity for its spectral class.<sup>1</sup>

Short-period RS CVn-like systems, through their rotational modulation, could give us information about the morphology and three-dimensional spatial distribution of stellar coronae. Possible detection of rotational modulation in

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the EUV light curve of HR 1099 was reported by Drake et al. (1994), with a minimum flux occurring near the phase when the G5 star is in front ( $\phi \approx 0.5$ ), consistent with a previously reported correlation between binary phase and X-ray intensity by Agrawal & Vaidya (1988).

Following previous MUSICOS campaigns on HR 1099 (Foing et al. 1994) the main goals of this campaign were to monitor for flares and to observe chromospheric lines in order to diagnose the energetics and velocity dynamics. Also photospheric Doppler Imaging and the study of chromospheric activity variations were planned.

## 2. Observations

The spectroscopic observations have been obtained during the MUSICOS 1998 campaign (Nov-Dec), involving OHP, SAAO, La Palma, Kitt Peak, ESO La Silla, Mt Stromlo, Xinglong and LNA, using both Echelle and Long Slit Spectrographs. A summary of the sites and instruments involved in the campaign and some of their most important characteristics can be found in Oliveira (2001). The spectra have been extracted using the standard reduction procedures in the IRAF package. The wavelength calibration was obtained by taking spectra of a Th-Ar lamp. The spectra have been normalized by a low-order polynomial fit to the observed continuum. Finally, for the spectra affected by water lines, a telluric correction have been made.

The X-rays observations were obtained with the all-sky monitor (ASM) detector on board RXTE (Levine et al. 1996). The ASM consists of three similar scanning shadow cameras, sensitive to X-rays in an energy band of approximately 2-12 keV, which perform sets of 90 s pointed observations ("dwells"). The analysis presented here makes use of light curves from individual dwell data. Light curves are available in three energy bands: 1.5-12 KeV, 3.0-5 and 5-12 keV. Between 5-10 of individual ASM dwells of HR 1099 were observed daily by RXTE, during MUSICOS 1998 campaign. The data were binned in 1 hour intervals.

## 3. Results

HR 1099 was observed almost continuously during the campaign, approximately 3 weeks in the optical and X-rays range.

During the campaign, two flares were observed, one at JD 2451145.51 (28-11-98) lasting about 0.63 days and a second flare at JD 2451151.07 (03-12-98) lasting about 1.1 days. This second flare shows an increase in the  $H\alpha$  emission line,  $H\beta$  and  $HeI D_3$  lines turns into emission during the flare and it also shows a strong filling-in of the  $NaI D_1, D_2$  line (see top Fig 1). Increase in  $Ca II H$  &  $K$  lines, filling-in of the  $MgI b$  triplet lines and  $HeI \lambda 6678$  turning into emission during the second flare were also observed.

In the middle panel of Fig 1 we plot the radial velocity curves of the binary system HR 1099, calculated using photospheric lines. We have also plotted the radial velocity for the two monitored flares, calculated using  $H\alpha$ . As a result, we notice that during both flares, the radial velocity is slightly displaced (15-20

km s<sup>-1</sup>) compared to the center of gravity of the primary. This result could be due to the fact that both flares had taken place near the limb.

The bottom panel of Fig 1 shows the  $EW_{H\alpha}/EW_{H\beta}$  ratio as a function of Julian date and as a function of phase. During quiescent phase we obtained values around 1 for the  $EW_{H\alpha}/EW_{H\beta}$  ratio, while during the first flare we obtained values slightly bigger than in the quiescent phase (2-3). During the second flare the ratio even reaches values of 8.

In the top panel of Fig 2 we show the equivalent width as a function of Julian date and as a function of phase for several chromospheric lines. From these results we observed that, although both flares shown an increase in  $H\alpha$  emission, the second flare produced a bigger increase. We have also observed that the first flare shows filling-in of  $H\beta$  but for the second flare this line turns into emission. Another remarkable feature is that the NaI D<sub>1</sub>, D<sub>2</sub> lines have a strong filling-in during the second flare. Note that both flares took place at around the same phase (0.85), but ~6 days apart. Note also that we have detected rotational modulation of the HeI D<sub>3</sub> line that could be attributed to the pumping of the HeI line by coronal X-rays from active regions.

The long light curve of HR 1099 (bottom panel Fig 2) display evident variability on short and long time-scales. Additional to the flare at JD 2451151.07, several other possible flares, not observed in the optical range, can be seen (e.g., at 2451141.49 d, 2451155.21 d, 2451157.62 d and 2451159.54 d). An additional feature of the light curve that we interpret as rotational modulation is seen around JD 2451155.21. The X-ray flux appear to peak at  $\phi \approx 0.27$ , after, the flux diminishes until it reaches a minimum value when the G5V star is in front of the active K1IV star ( $\phi=0.5$ ), in agreement with Drake et al. (1994). The strong variability from one rotational period to other may suggest that long-term flaring is involved. These effects are observed in all the energy bands. The flare at JD 2451151.07 shows an increase in the S band (1.5-12 keV). However, the medium energy band (3-5 keV) nor the high energy band (5-12 keV) show any clear evidence for variability suggesting this to be a soft X-rays event only. The optical flare at JD 2451145.51 was not observed in any of the X-rays bands. Spectral hardness analysis does not show clear signatures of heating and cooling.

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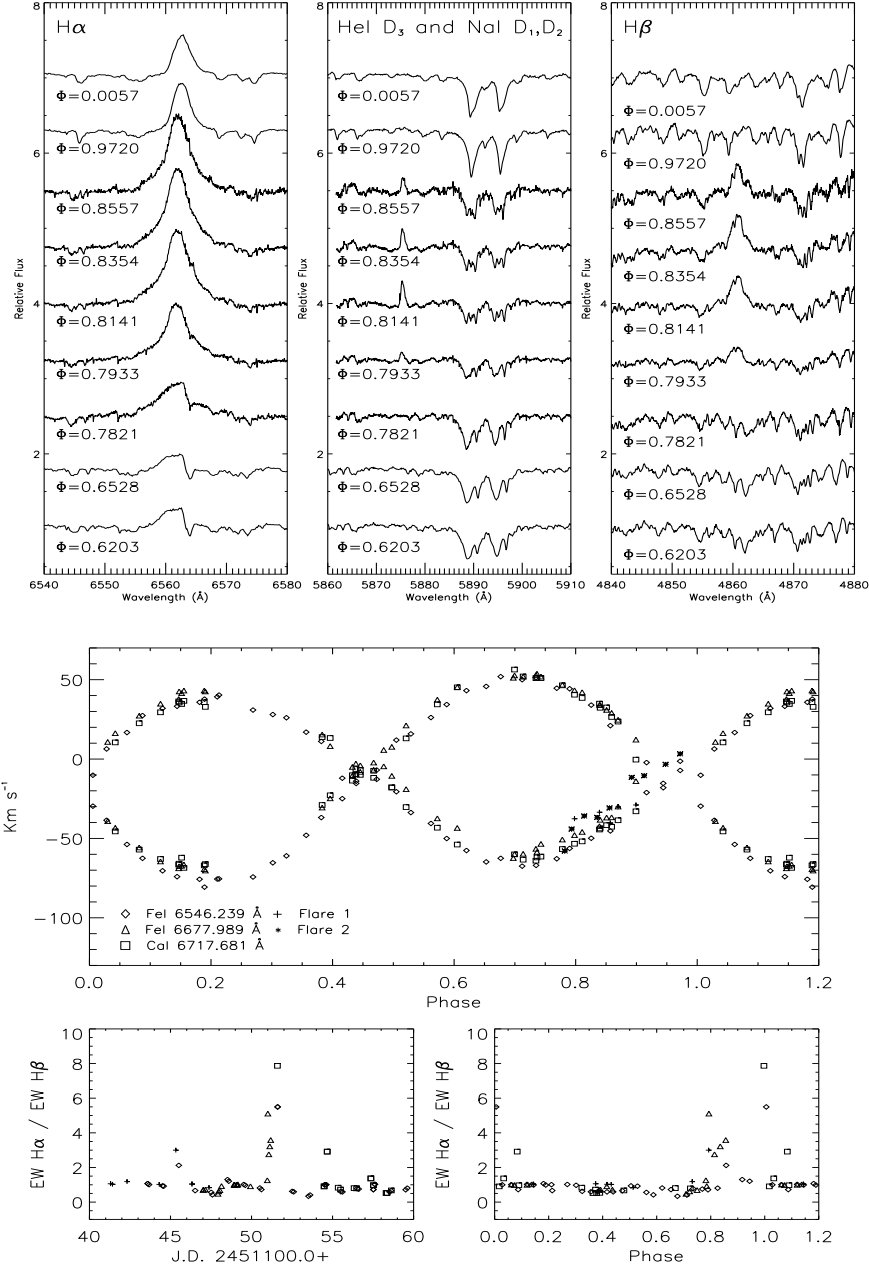


Figure 1. Top panels: The observed spectra for H $\alpha$  (left panel), HeI D<sub>3</sub> and NaI D<sub>1</sub>, D<sub>2</sub> (middle panel) and H $\beta$  (right panel) of the second monitored flare starting at JD 2451151.07 arranged in order of the orbital phase. Middle panel: The radial velocity curves of the binary systems HR 1099, calculated using photospheric lines. Bottom panels: The EW<sub>H $\alpha$</sub> /EW<sub>H $\beta$</sub>  ratio as a function of Julian date and as a function of phase.

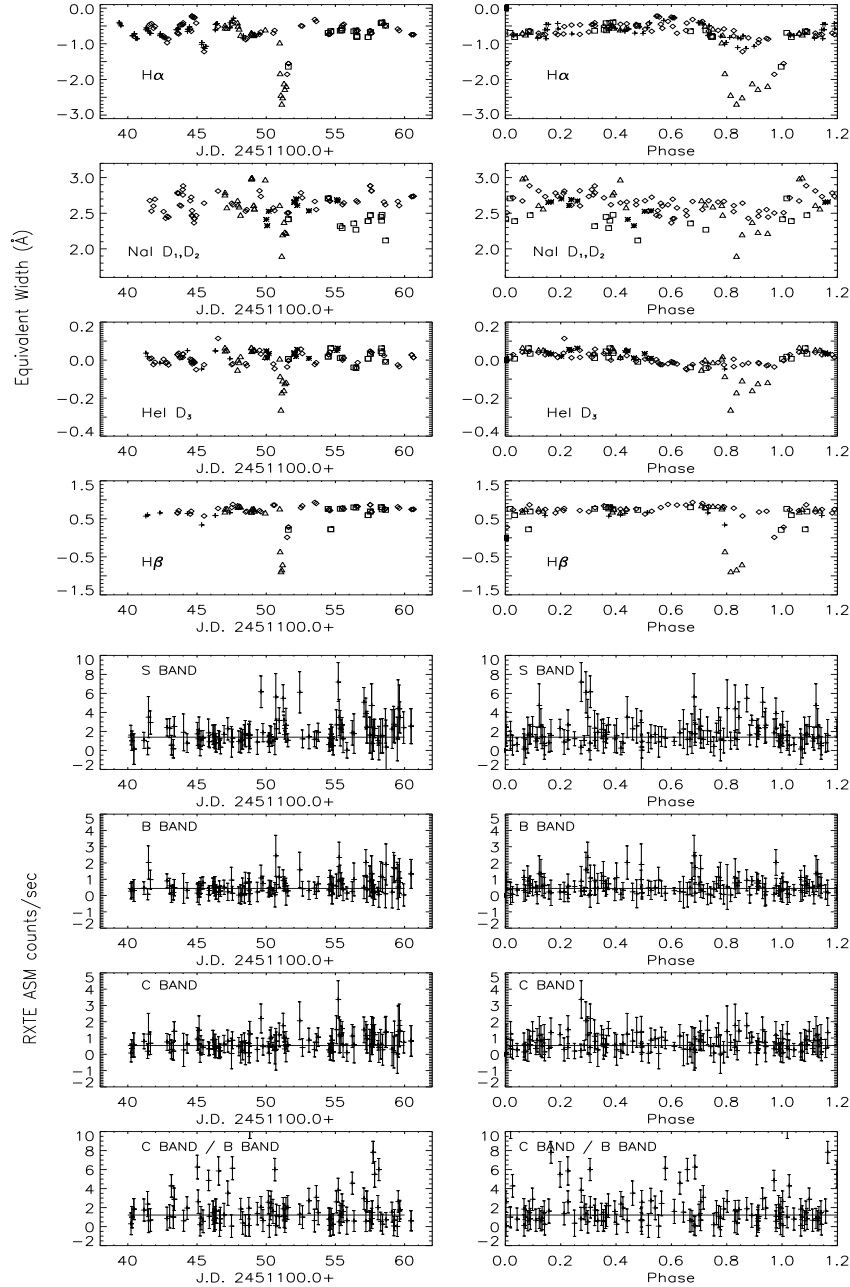


Figure 2. Top panels: The equivalent width as a function of Julian date and as a function of phase for H $\alpha$ , NaI D<sub>1</sub>, D<sub>2</sub>, HeI D<sub>3</sub> and H $\beta$  lines. Bottom panels: Light curve observations of HR 1099, from the ASM instrument on RXTE satellite, obtained at the same time as the MUSICOS 1998 campaign. The band S (1.5-12 keV), band B (3-5 keV), band C (5-12 keV) and hardness ratio C/B as a function of Julian date and as a function of phase are shown.